QPS Photonics

VibroFibre™

Next Generation Stator End Winding Monitoring Solution

Application Note



CONTENTS

- SEW Background
- VibroFibre™ Advantages
- The TATA Bhire Project
- The Next Generation Solution

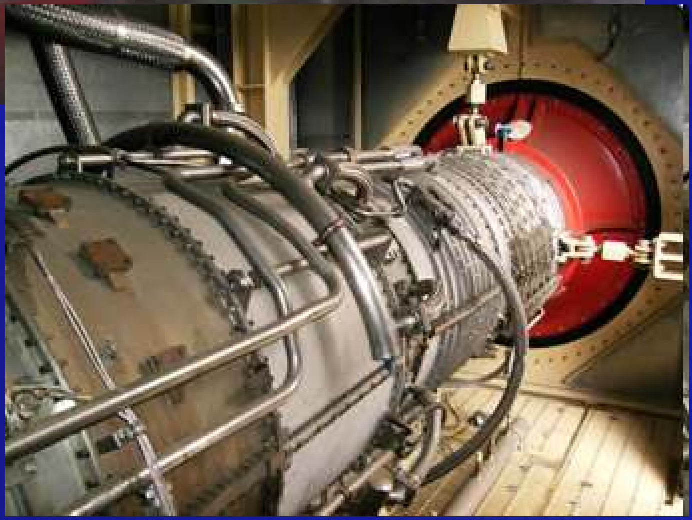
Stator End Winding Background

Hydrogen Cooled Generator →





Stator End Winding



Gas Turbine

The Problems

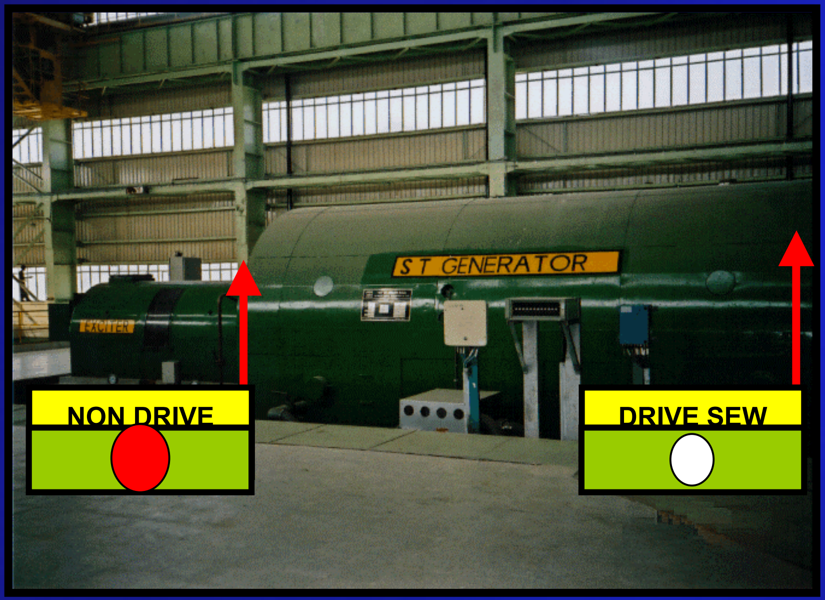
- A generator's electrical copper formers are secured with resin and wedges in their stator slots
- Over time, the resin frets away resulting creating small gaps allowing increasing conductor movement
- These gaps cause bending stresses in the windings and softens insulation rigidity as well as breaks it down
- Bending makes copper work harden and then fractures
- End windings protrude from the stator and hence are most subject to bending stresses
- Excessive vibration and thermal cycling weakens insulation; causes SEW bar fractures



Stator End Winding Monitoring Prime Objectives

1. To maintain power generation
2. To prevent insulation breakdown, failure and possible combustion
3. To monitor the condition of the generator windings for rigidity
4. To indicate maintenance improvements when windings are reconditioned or ‘tightened’

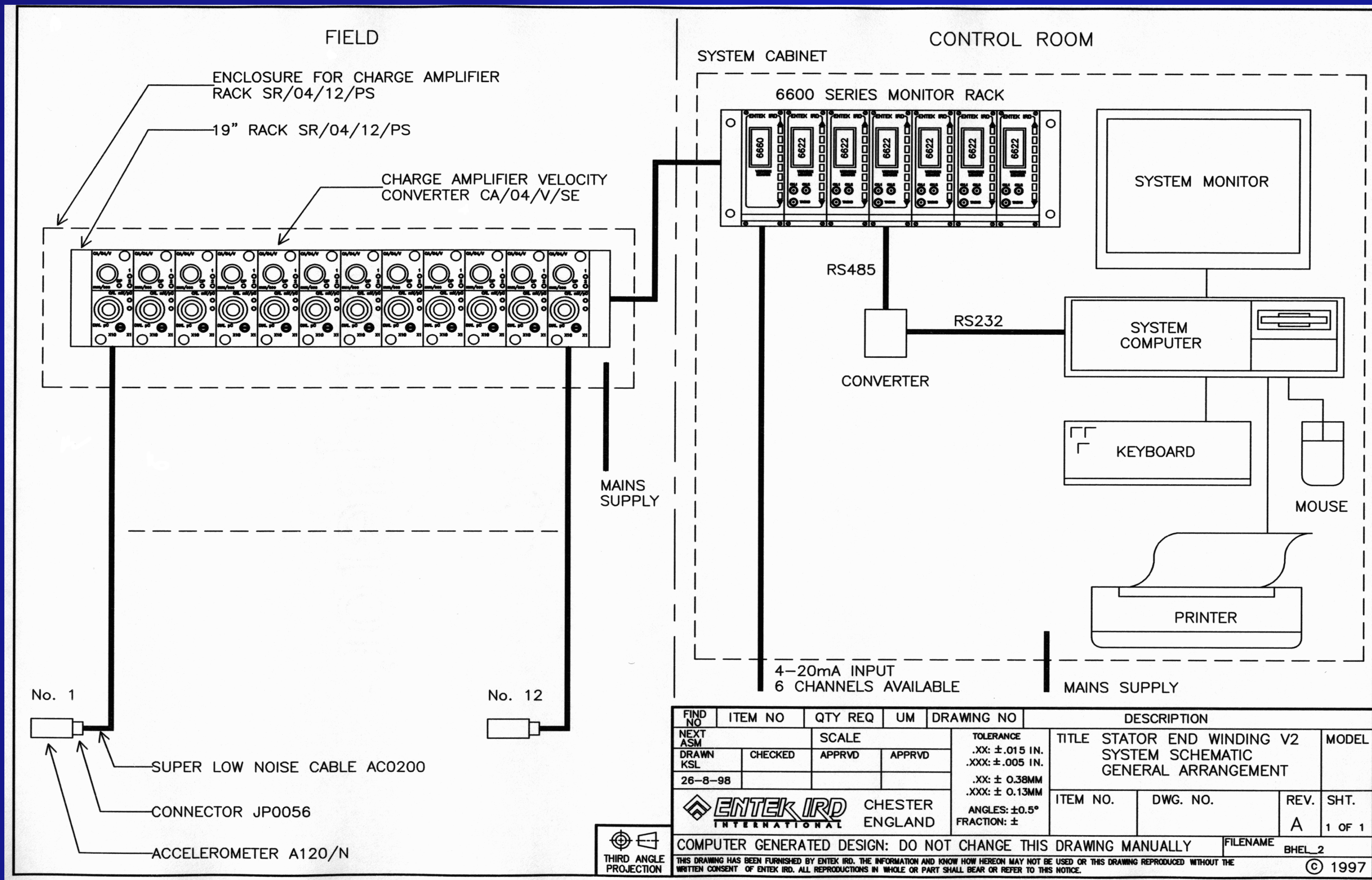
Past Solutions and Issues



A Typical Hydrogen Cooled Generator

- Absolute deflection is measured in microns by accelerometers
- Accelerometers are mounted on the windings but are prone to electromagnetic effects and noisy signals
- More modern installations are hydrogen cooled which is an inherent explosive environment , extra safety precautions are essential
- Fitting sensors to windings is a complicated invasive operation and usually done on new Generators by the OEM

An example of Old Generation Solution -- MIL SEW3 System



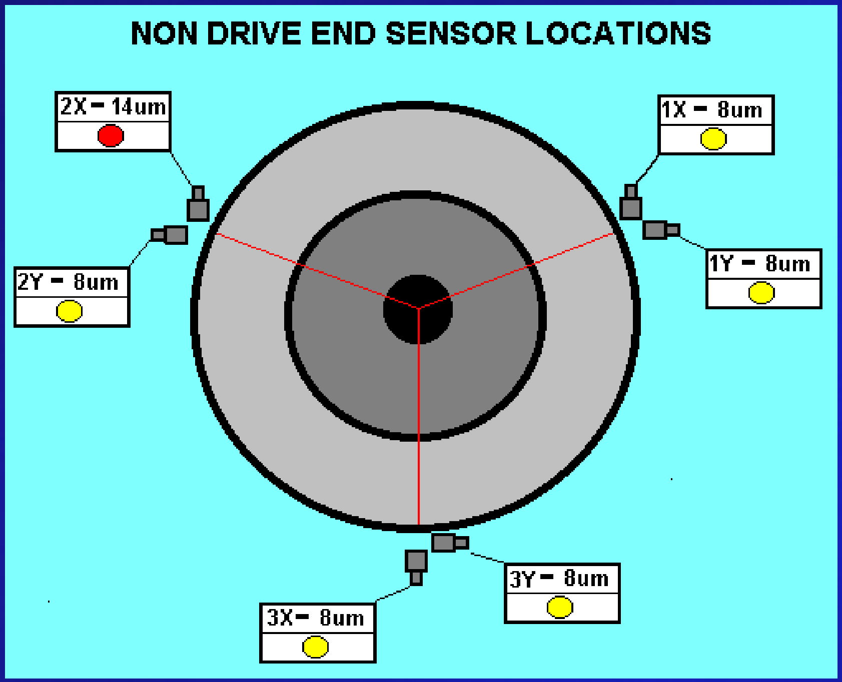
SYSTEM SCHEMATIC

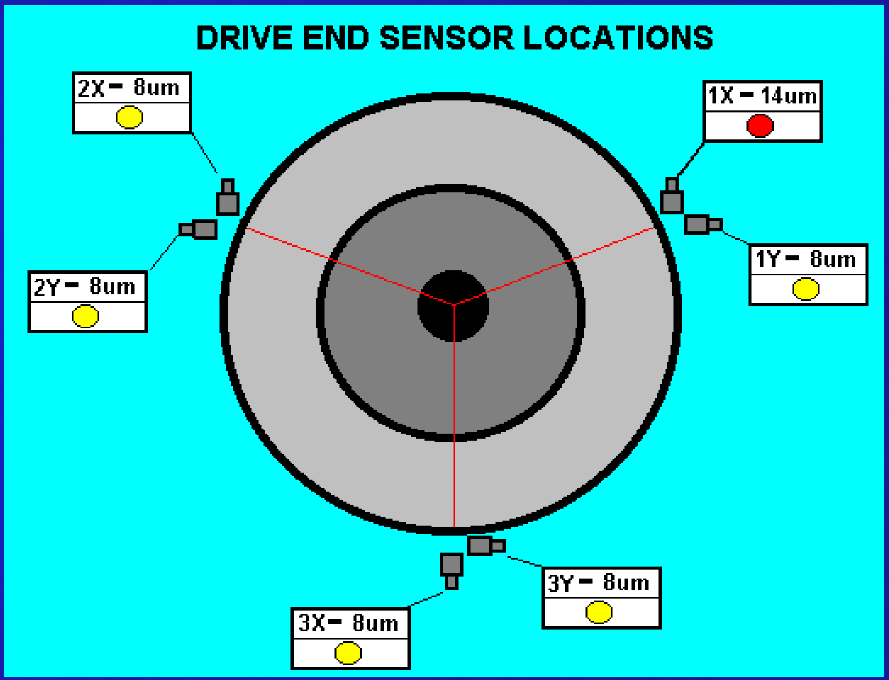
MIL SEW1-3: Technical Details

MAIN COMPONENTS OF AN SEW SYSTEM

- **ACCELEROMETERS**
- **CHARGE AMPLIER – filtering**
- **IS BARIERS**
- **VIBRATION MONITOR MODULE**
- **Cabinet & Cables**
- **Optional:**
- **PERSONAL COMPUTER**
- **SOFTWARE**

Stator End Winding Accelerometer Matrix
Accelerometer Locations





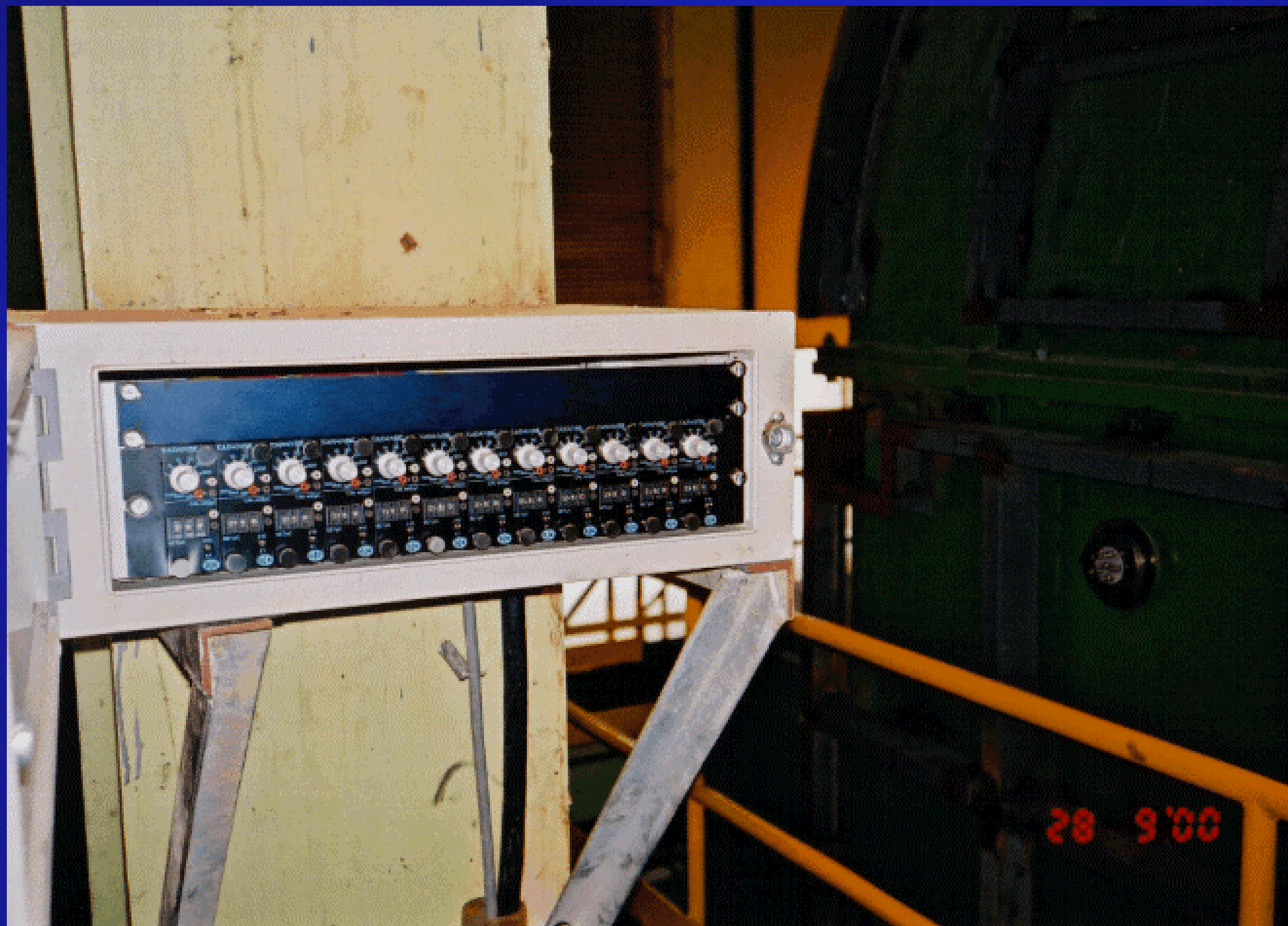
- Sensors need to measure radial and tangential vibrations and are position at each end of the generator at the minimum voltage point
- Locations 120 degrees apart are considered economic
- Attaching accelerometers to the winding can be invasive and is usually done by the OEM during the winding installation process

Sensors Terminating at Generator



The Accelerometers terminate at the BNC sockets ensuring sealing to contain the hydrogen. They connect to the Charge Amplifiers

Charge Amplifier in Site Mounted Cabinet



The Charge Amplifiers is for 12 Channels in an IP65 Cabinet

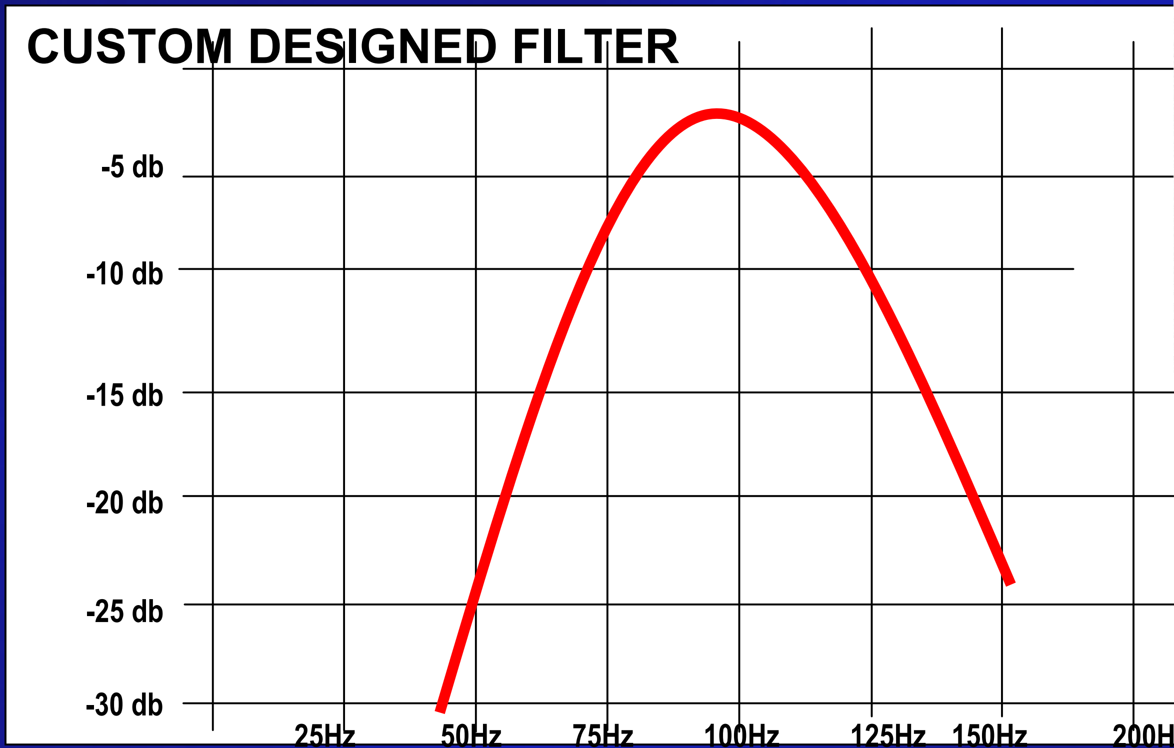
The Charge Amp – 1st Stage of Integration - PN CA/04/V/SE

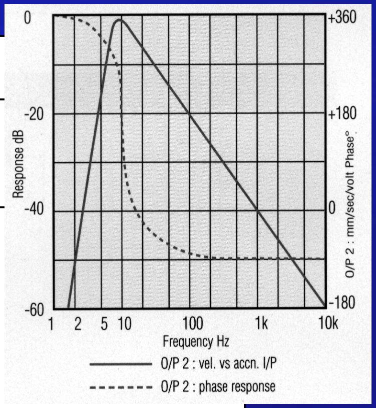
KEY CHARACTERISTICS

INPUT	single ended
MAX INPUT CHARGE, Nc	12
IMPUT CAPACITANCE LOADING	10nf=1% gain reduction
NORMALISING RANGE pC/g	1/100
NOISE LEVEL @ 1pC/g	0.05mm/sec + 0.05/sec/1nf input capacitance
OUTPUTS 1 ACCN Mv/G	SINGLE ENDED 100+-2% @ 500hZ, 3DB BANDWIDTH 3hZ/100khZ
OUTPUT 2 VEL., SWITCH, SELECTABLE 10db mm/sec/V	1, 3.16, 10, 31.6, 100, 316 +- 3% @ 500Hz bandwidth 20Hz/10KHz
PEAK O/P VOLTS @ Vs=+-15V	+- 12V, O/P's 1&2
PEAK O/P CURRENT O/P 1&2, Ma	+- 10
OUTPUT IMPEDANCE, O/P 1&2	<10 ohms + 47uF
SUPPLY VOLTAGE Vs, V	+- 10/15
SUPPLY CURRENT, Ma	+- 15



The Charge Amplifier Filter Characteristics

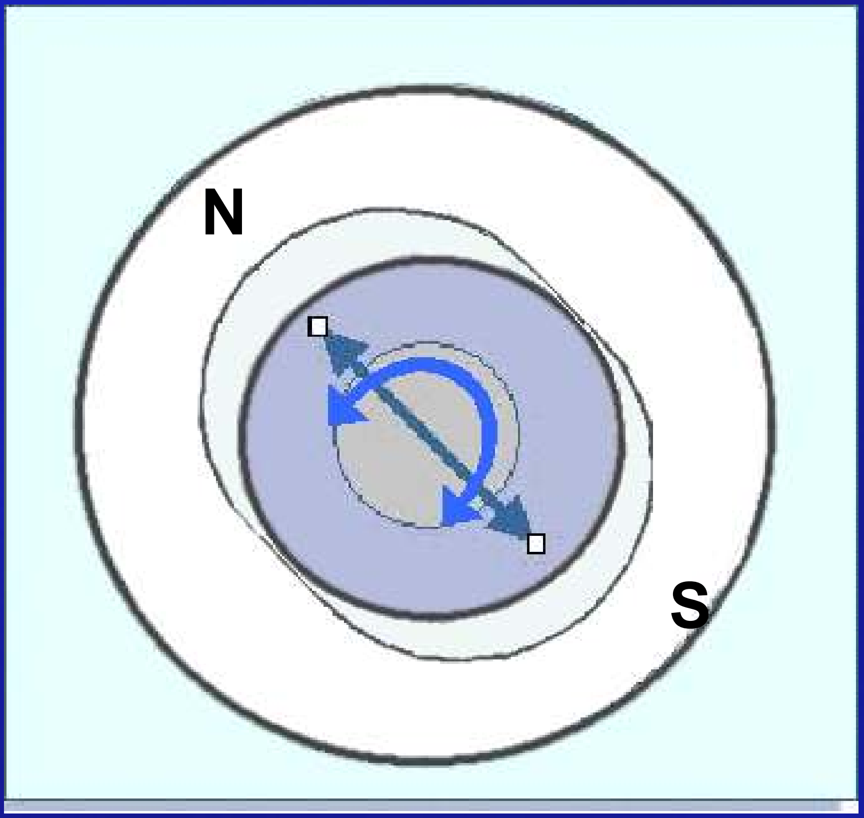




- SEW is a structural monitoring system. The Windings are excited by 50Hz
- The Stator Core vibrates at 2x Synchronous frequency. Increasing levels indicate deterioration.
- A filter from 80 to 120 Hz gives a central frequency of 100Hz allowing for slight frequency variations to give the optimal value of the measured area

Why Measure at 2xLF or 100Hz?

- Most generators are two pole
- The two poles produce double the fundamental frequency each revolution
- Hence at 50Hz, the core will vibrate at 100Hz
- Monitoring the 100Hz frequency over time is a direct indicator of end winding condition when related to load



Large Overhangs Vibrate at 2 x Synchronous Frequency

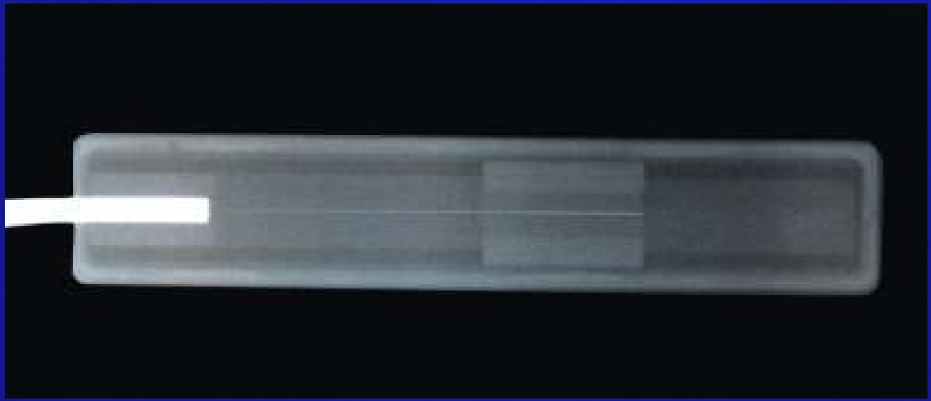


A GEC Photo

VibroFibre™ Advantages







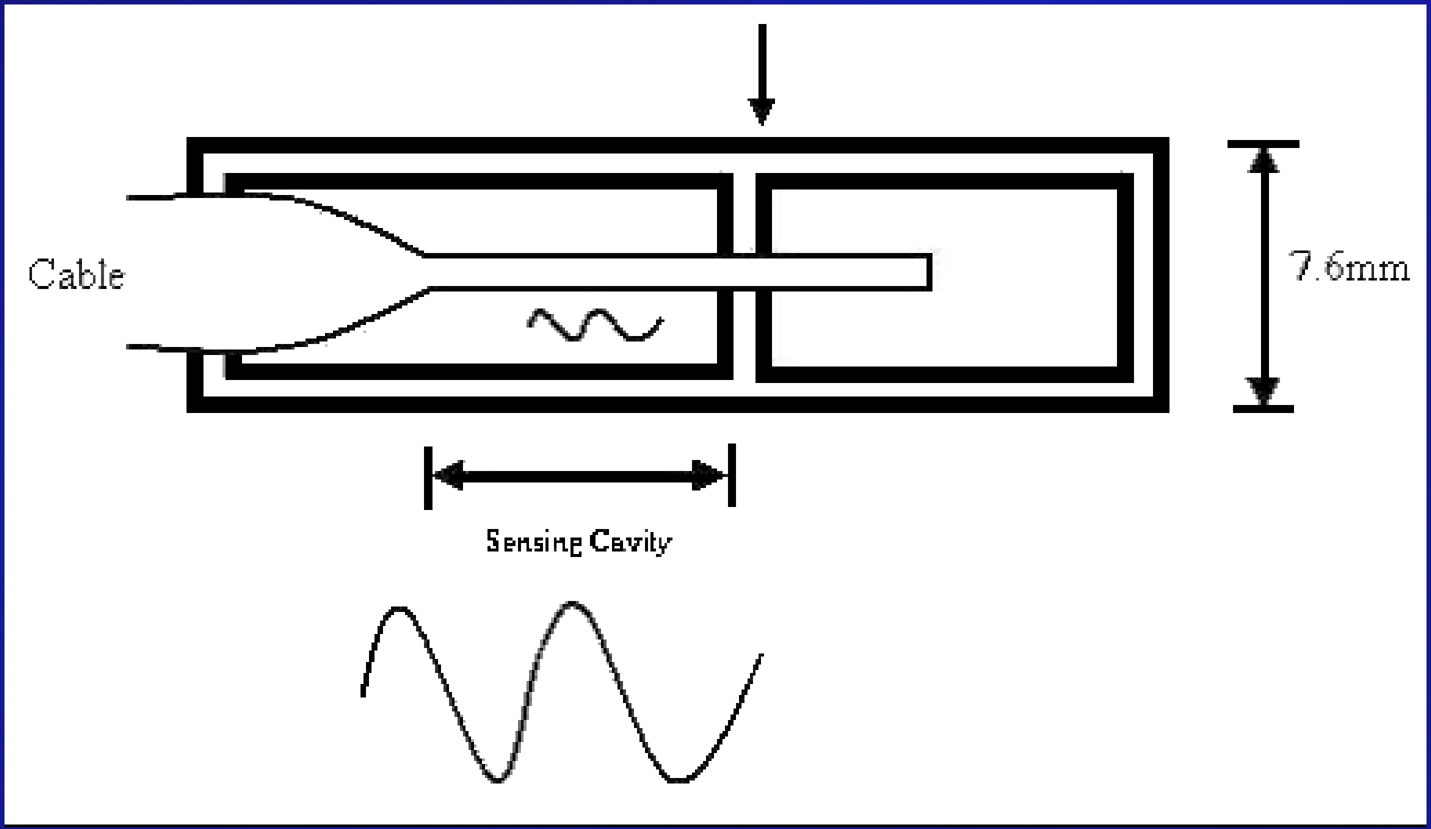
Packaged in polycarbonate that can be secured with adhesive.

The X-Ray shows the FBG treated fibre

How Does VibroFibre™ Work?

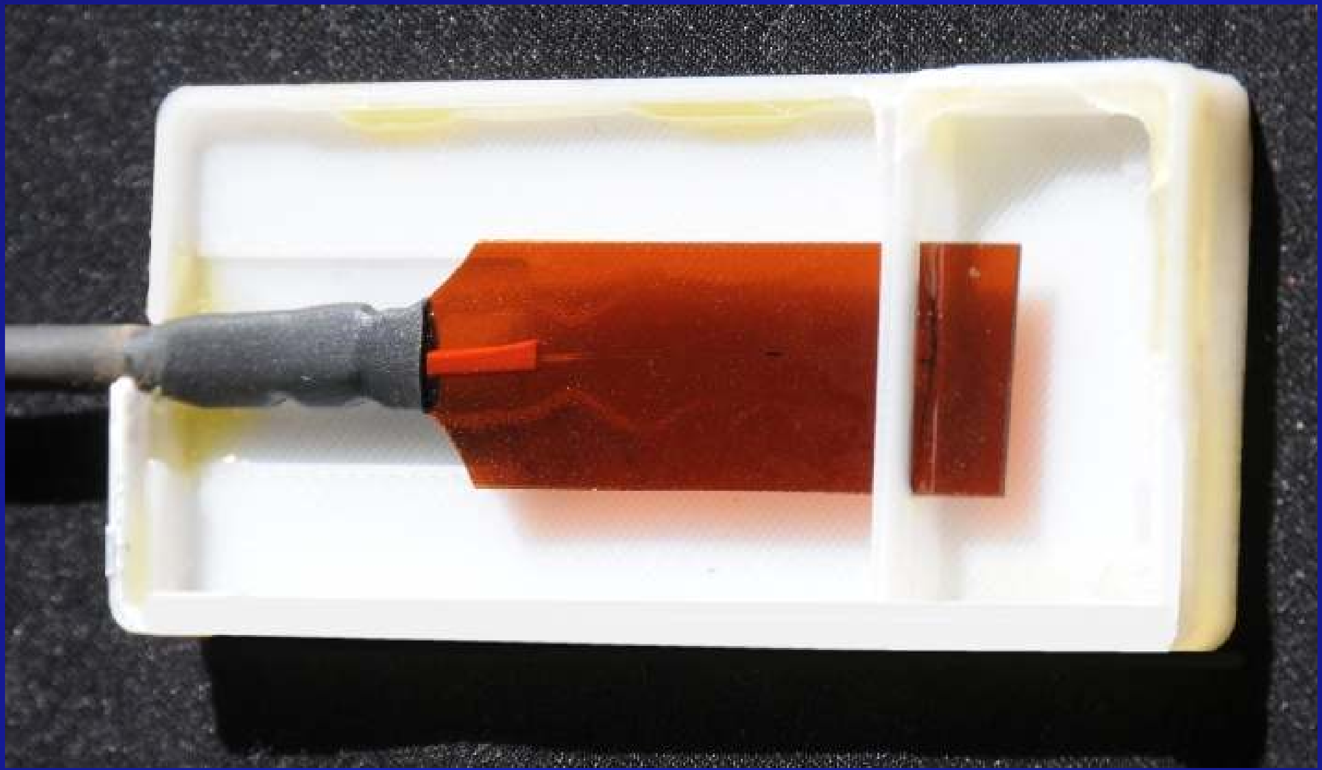
- VibroFibre™ Technology is based on the detection of distortion of a fibre optics cavity.
- When a vibration signal is present and is properly coupled, it causes the optical path to change.
- For high frequency surface waves, the package material must not absorb the signal so is tightly coupled against the substrate with silicon gel.
- For the monitoring of turbine generator, the signals are low in frequency.
- Sensors respond to such low frequencies, typical 100Hz with the help of a mechanical amplifier.

Fully Encapsulated VibroFibre™ Sensor



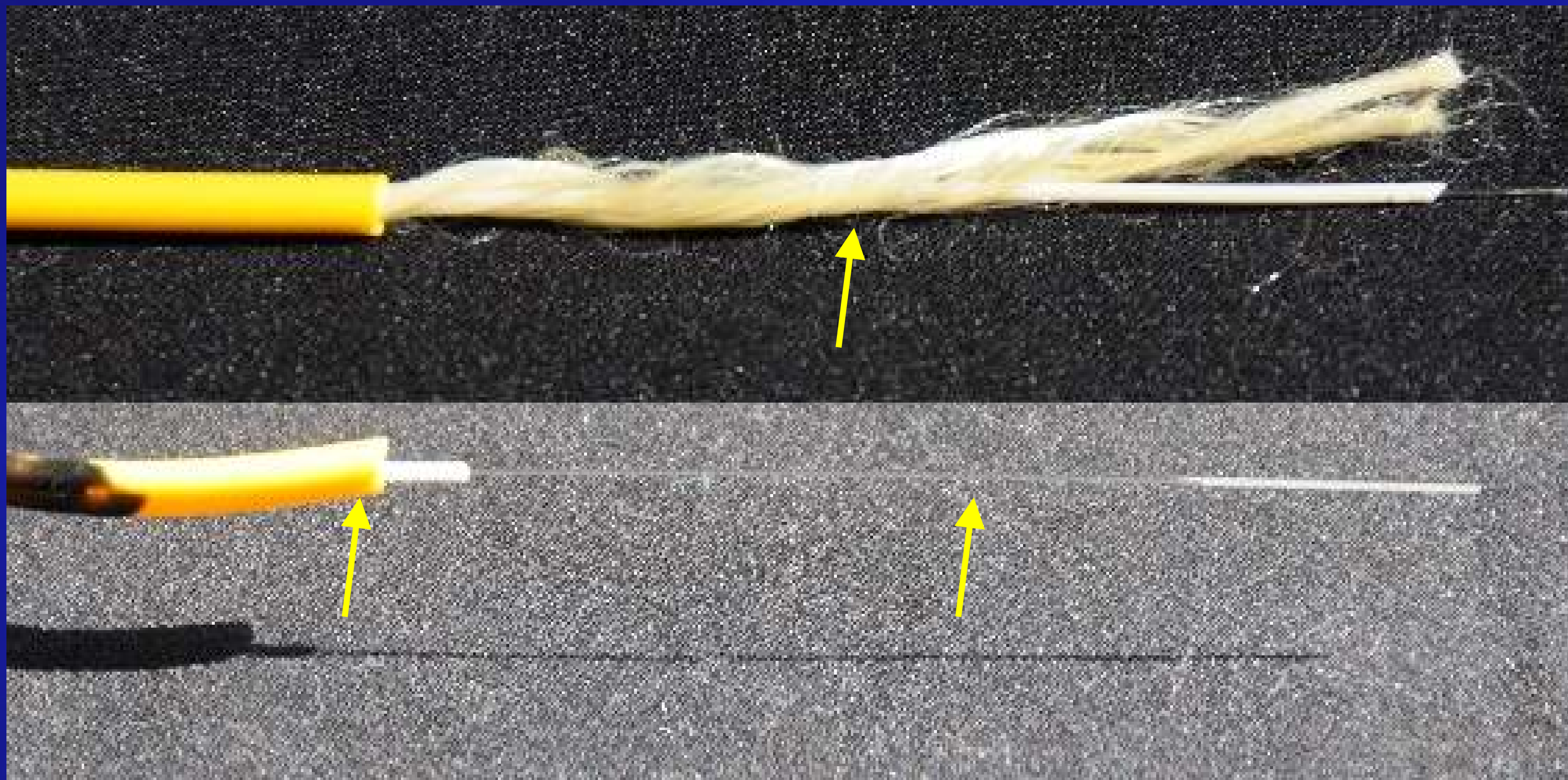
By applying two identical caps, one top, one bottom, we have created a dustproof, oil proof environment for the sensor head.

Inside the Encapsulated VibroFibre™ Sensor



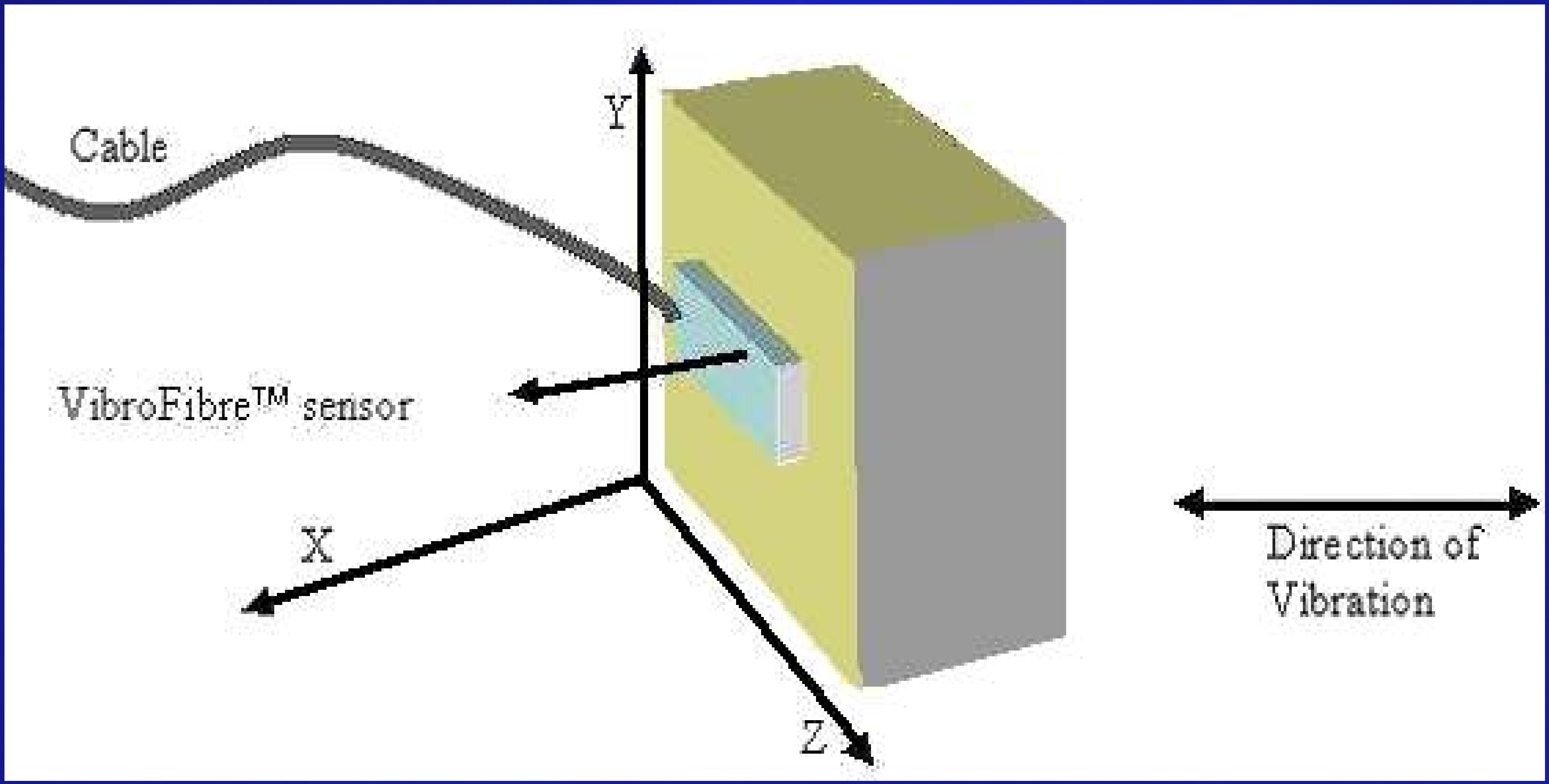
- By applying two identical caps, one top, one bottom, we can create a dustproof, oil proof environment for the sensor head.
- The material used in such encapsulation is a special high temperature ABS Plastic. It will stand up to and operating temperature of 100°C.
- The sensor is self calibrating with a life of at least 25 years

Fibre Optics Cable



- To protect the fibre it is encased in a soft fibrous material around an inner sleeve making it impervious to reasonable external crushing
- The fibre optic core is specially treated
- FO installation requires special care and connection cleaning tools

Measures in Any Direction Selected



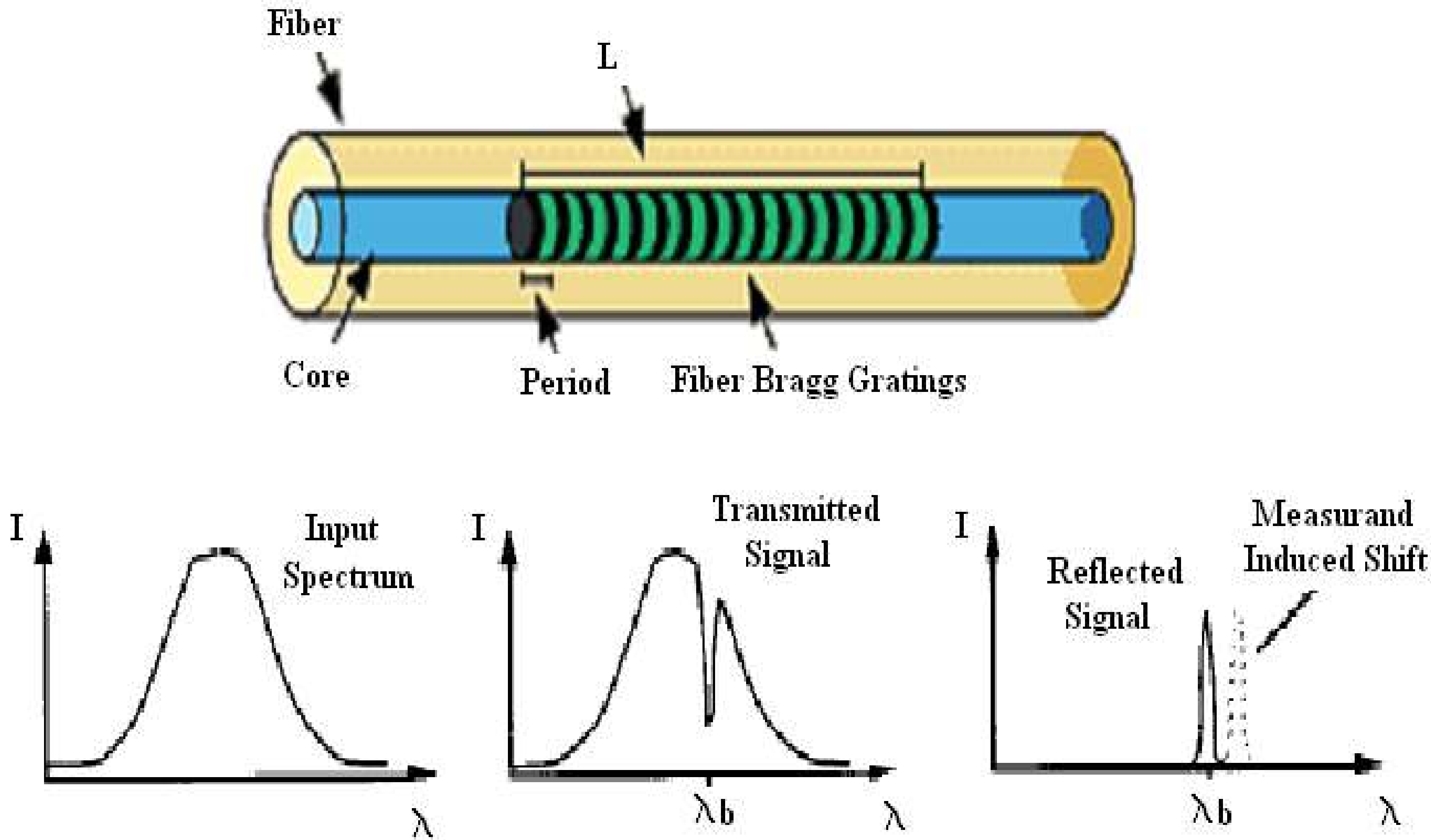
Why is VibroFibre™ Unique ?

- The Westinghouse FOVM fiber optic vibration monitor was patented in 1996
- It employs a light beam directed on a canterlever mounted grid (mirror) sensor
- The light beam is proportional to sensor's deflection and hence is an 'Optical-Mechanical device'
- The VibroFibre™ sensor is solid state in that it employs FBG on a single strand of specially treated optical fibre

What is FBG ?

- Applies 'Single-Mode' Fibre Bragg Grating (FBG) technology
- Gratings are tiny mirrors etched into the fibre that reflect laser light
- A pair of etched mirrors makes a cavity sensitive to vibration in the fibre
- Interference fringes are related to the amplitude and frequency of the vibration signal
- This provide a technology platform that can be used in many applications

FBG Technology

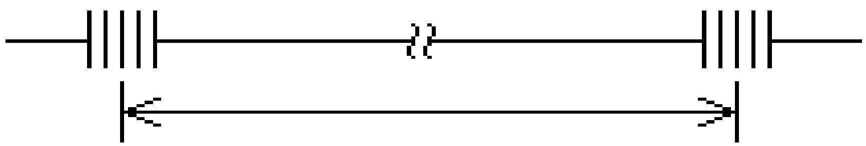


VibroFibre™ Sensor Ranges

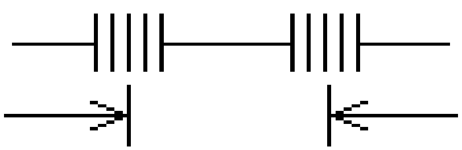
EDM FBG



Sensor head for Perimeter Security
such as piplines, wind turbine blades



Medium length cavity, 0.1 ~ 10m
Sensor head for impact studies



Small cavity, 2 ~ 5mm
Sensor head for dynamic strain, presure,
high speed vibration as well as AE

Features of VibroFibre™

- Sensing mechanism in standard glass fiber
- Low loss sensor head made with twin FBGs
- Glass material is inert , passive, draws no power, hence intrinsically safe
- Sensors form a Star Network up to 128
- Mature technology with volume capacity
- Small size light weight , simple packaging
- Broad band frequency response of up to 3MHz
- Sensitivity can be optimized by cavity length

Interrogation Method for VibroFibre™

- Based on mature DFB laser Technology originated from the telecom industry
- Ideal for parallel measurements at high speed
- Optical vibration signal converted to analog voltage output
- Plugs into existing Data acquisition systems for complex signal analysis, modal analysis and pattern recognition.
- No new training or software development required
- Each laser can easily support 8 channels, with programmable signal conditioning

The TATA Bhira Project

- In 2007, the TATA specification called for a fibre optic vibration system to avoid electromagnetic radiation problems associated with accelerometer systems.
- The original systems involved accelerometers that were fitted on special brackets that have to be built into the stator end windings only when newly manufactured.
- The Fibre Optic approach solved many past problems but principally can be fitted on a generator at any time as it is non invasive and takes little outage time. Say 1 day.

TATA Bhira Hydro – Commissioned 1929

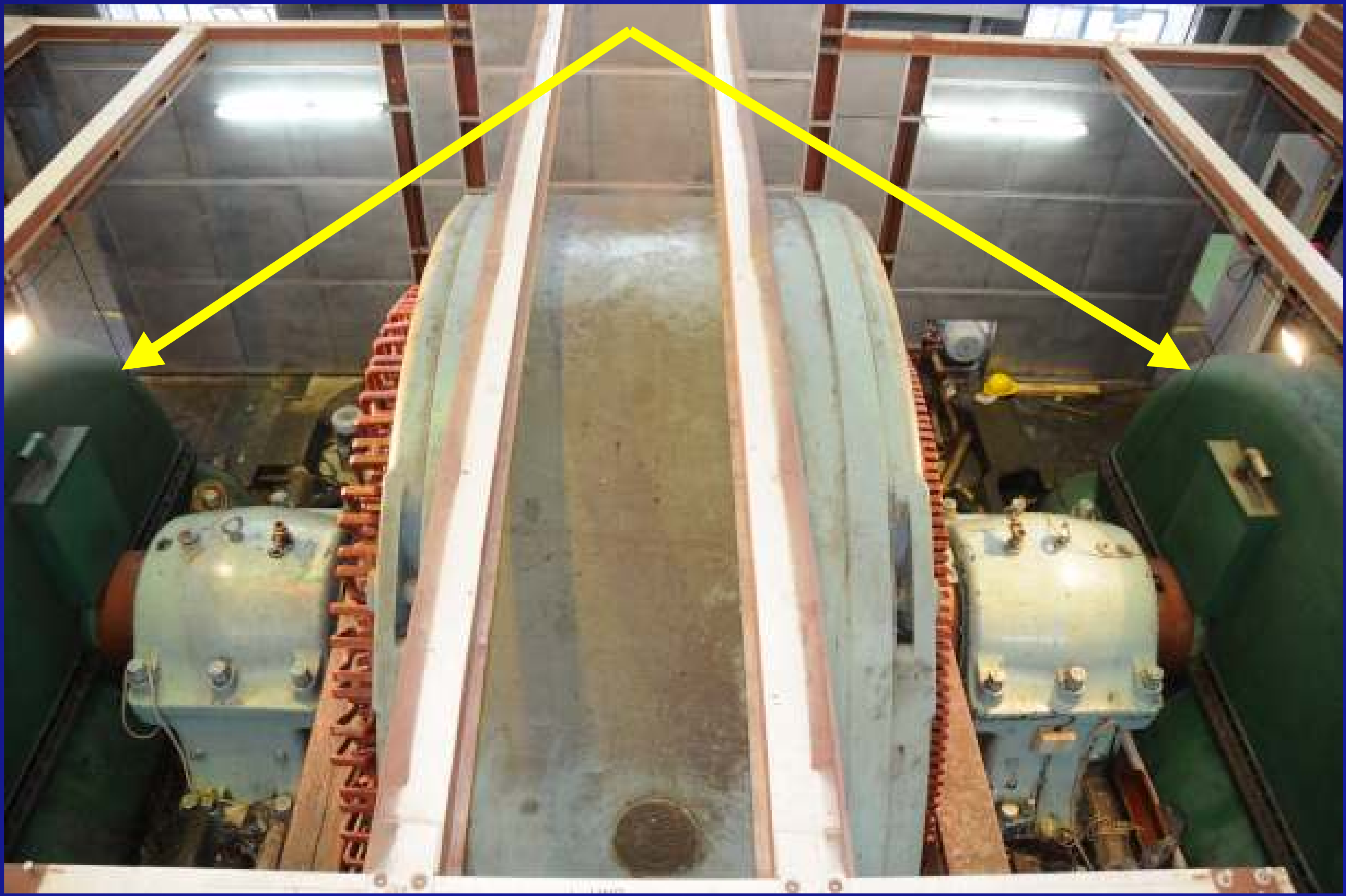




- **This Bhira site has 6 x 25MW Pelton type Generators installed**
- **The early English Electric units have been upgraded**

English Electric 25MW Hydro

Pelton Turbines Either Side of Generator



25 MW Horizontal Hydro Generator





Generator & Pelton Wheel

The Plant had experienced a winding failure on the Generator. Consequential damage was due to sudden high vibrations of the end windings



TG3 & TG4 Stator End Winding



Corrective action was taken using a putty resin to secure the windings from movement – there was a need to monitor the end windings

QPS Photronics Partners with Mechanalysis (India) Ltd

MIL has >30 years experience supplying machinery protection monitors in India, it had supplied 29 SEW systems to BHEL in the past using the older accelerometer technology.

- **Built upon their experience, QPS integrated VibroFibre™ system with MIL8800 on-line protection monitor (API670) to provide traditional plant communications. A partnership was born.**
- **TATA Projects of Mumbai were convinced that the MIL-QPS solution was superior to two other overseas bidders and was awarded the contract in Nov 2007. System commissioning was completed early March 2008 on two TGs.**



Cleaning the Generator Windings before mounting sensors for retro-fit

- **Subsequent improvements to sensor design and software were made during the warranty period as this World First development was done with co-operation with TATA Projects.**
- **After acceptance trials the system may be expanded to a further 4 TGs.**

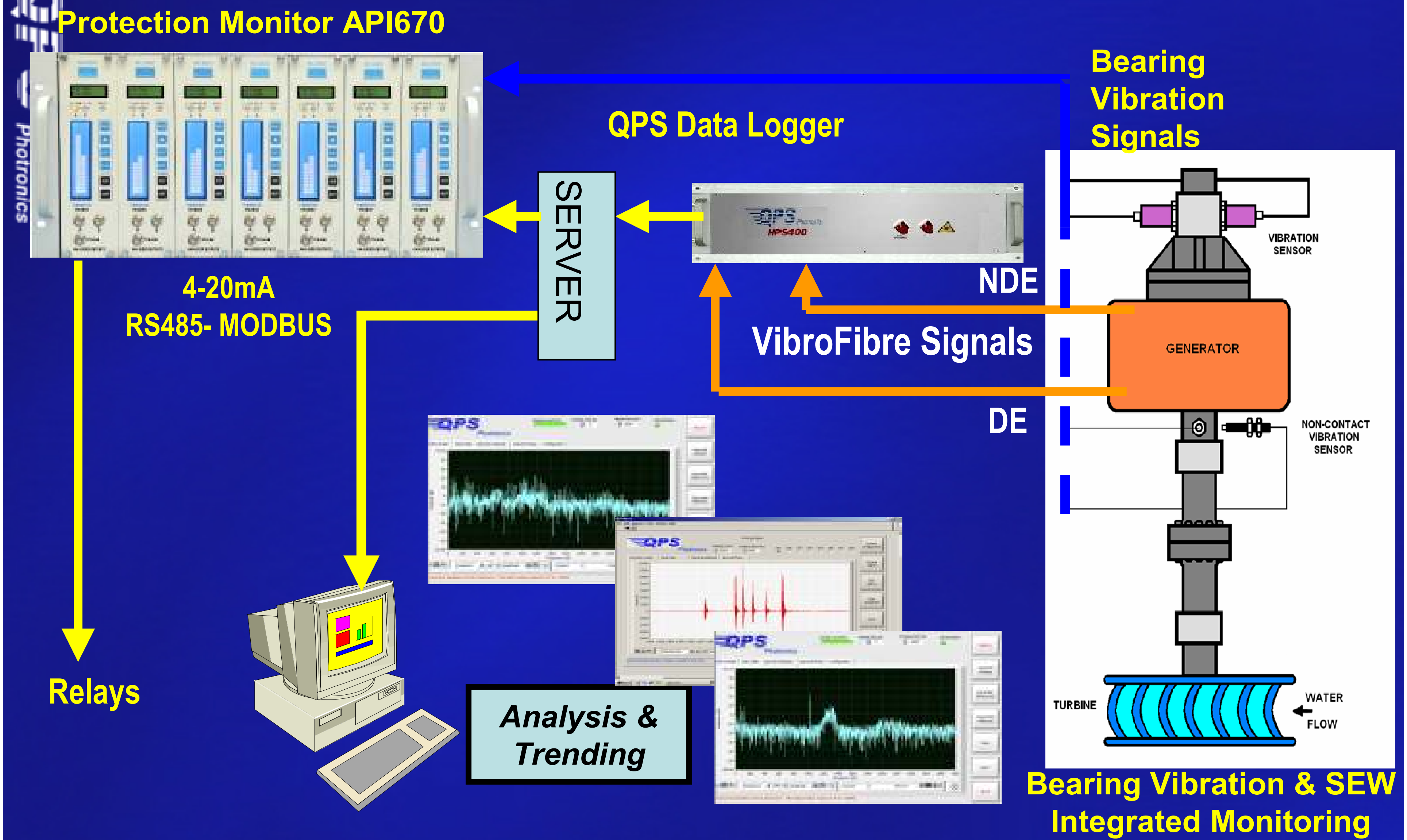
The Next Generation Solution

- Fibre Optic systems are now viable and cost effective, Fibre Optics make R&M projects viable
- In November 2007, QPS and MIL designed the Next Generation SEW based on fibre optics using FBG technology with MIL8800 termed SEW4 for Bhira project
- SEW4 was installed at TATA Bhira on TG3&4 in Feb08.

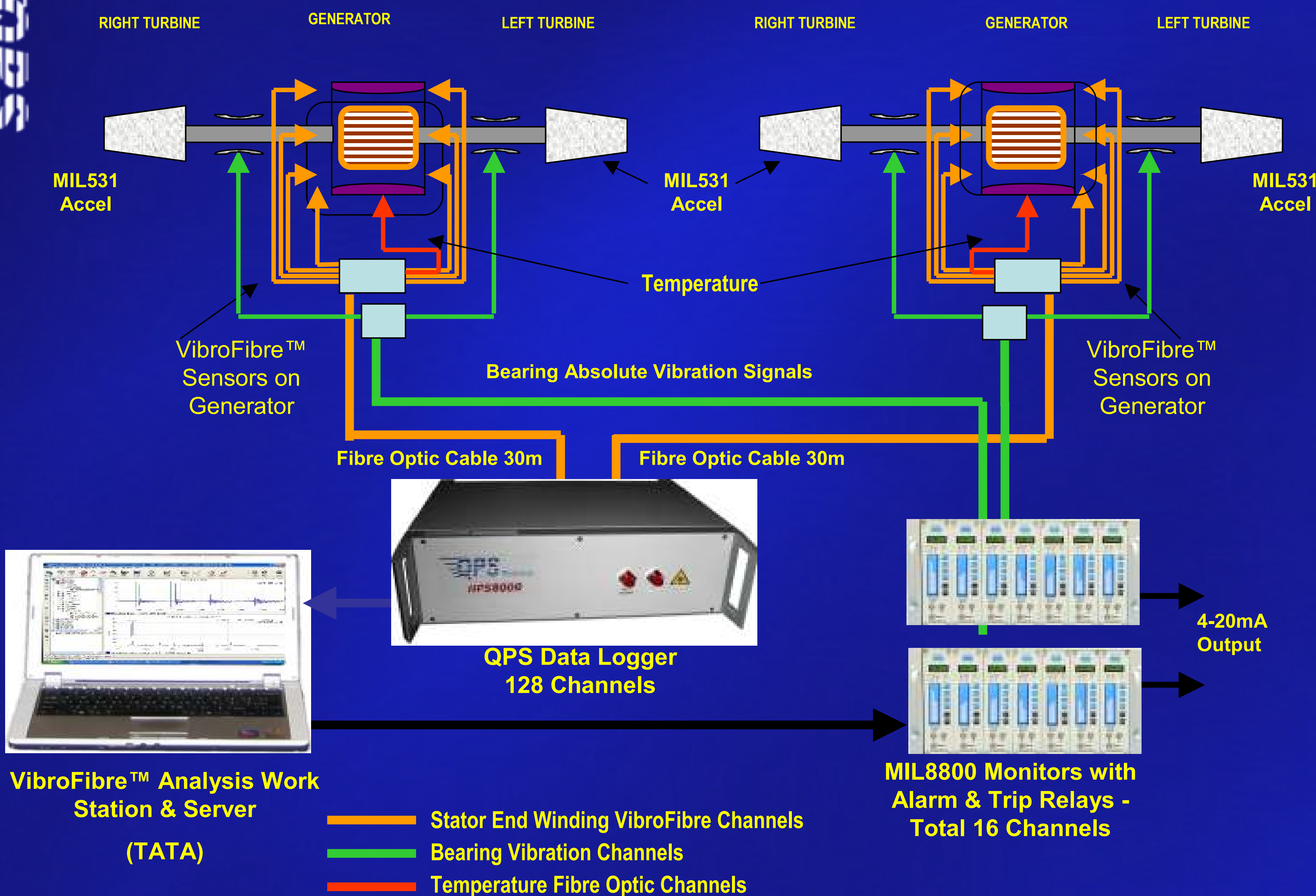
Why Fibre Optical Sensors for SEW Monitoring?

- The generator environment is a high magnetic field environment
- Many generators are hydrogen cooled & hence need intrinsic safety sensors
- Fibre Optic vibration sensors are inert and unaffected by magnetic fields
- Fibre optic sensor signal cables are not affected by the magnetic field
- Fibre optic sensors can be installed in a few hours
- Fibre optic sensors have a known life of 25 years
- Fibre optic sensors detect absolute vibration and reflect the status of the windings
- FO sensors do not require special signal conditioning or double integration and filtering
- FO sensors are self calibrating and produce a clean signal

MIL - QPS SEW Generic Architecture



TATA Bhira Hydro – VMS & End Winder Architecture for 2 Turbines



Sensor Calibration at Mechanalysis Mumbai Traceable to National Standards

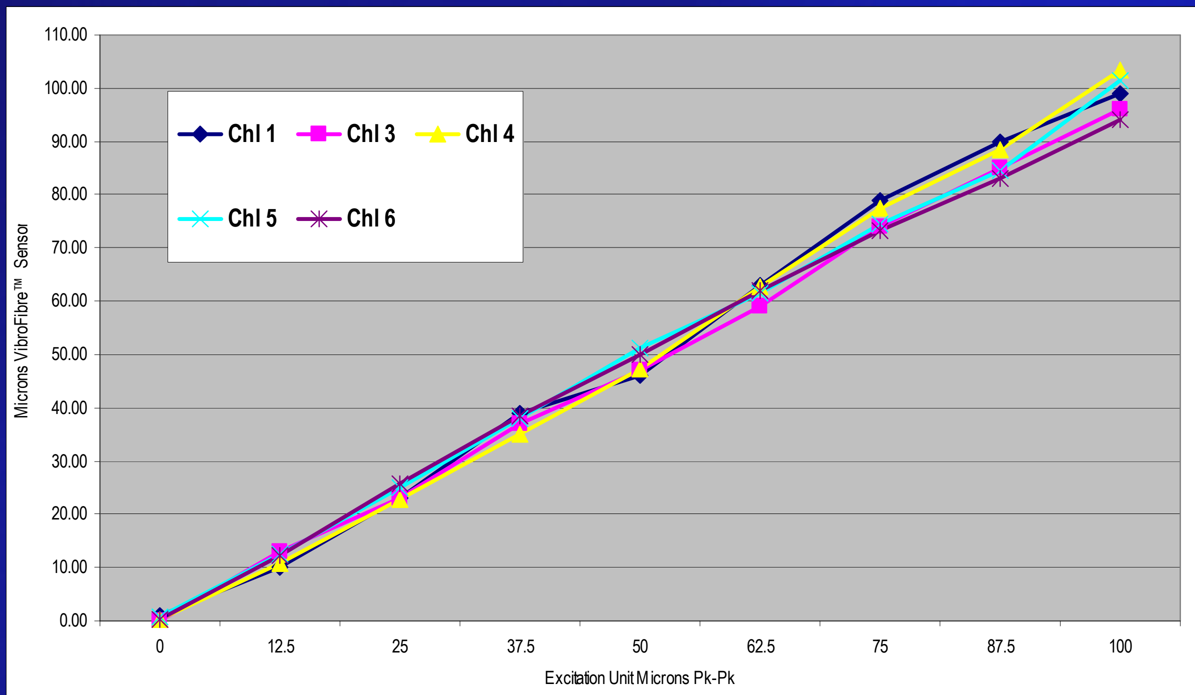
Pre-commissioning sensor tests at MIL Works



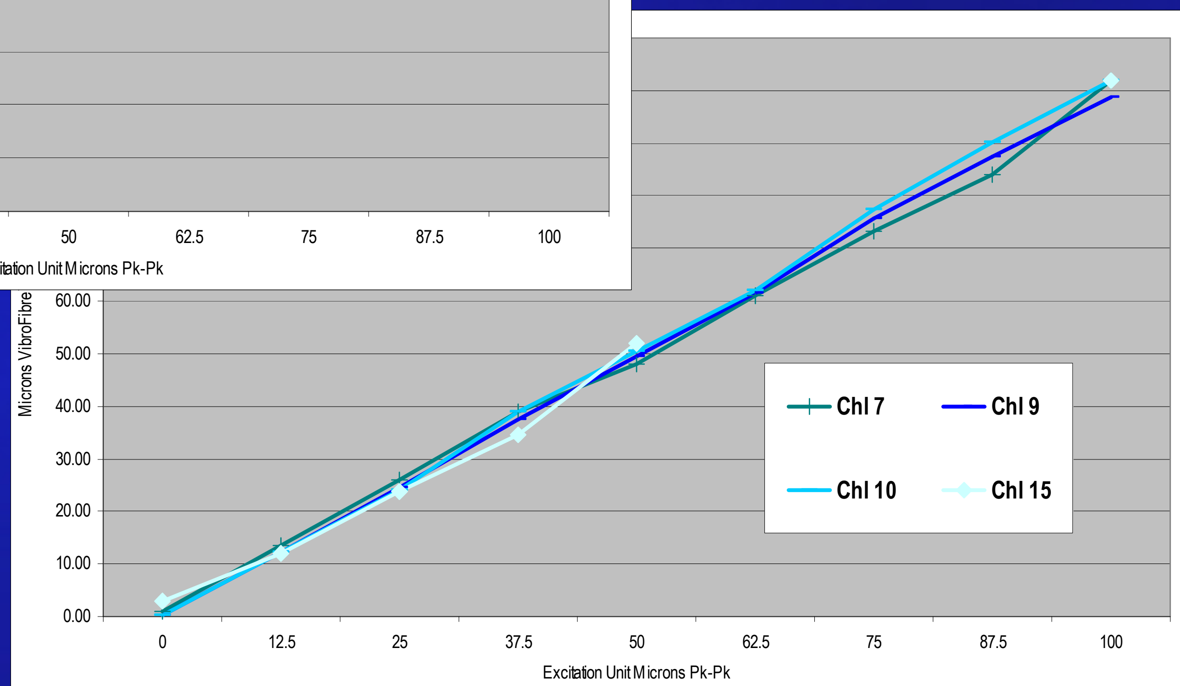


Multi-Stack Sensor Calibration for Consistency and speed of test

Sensor Calibration Graphs



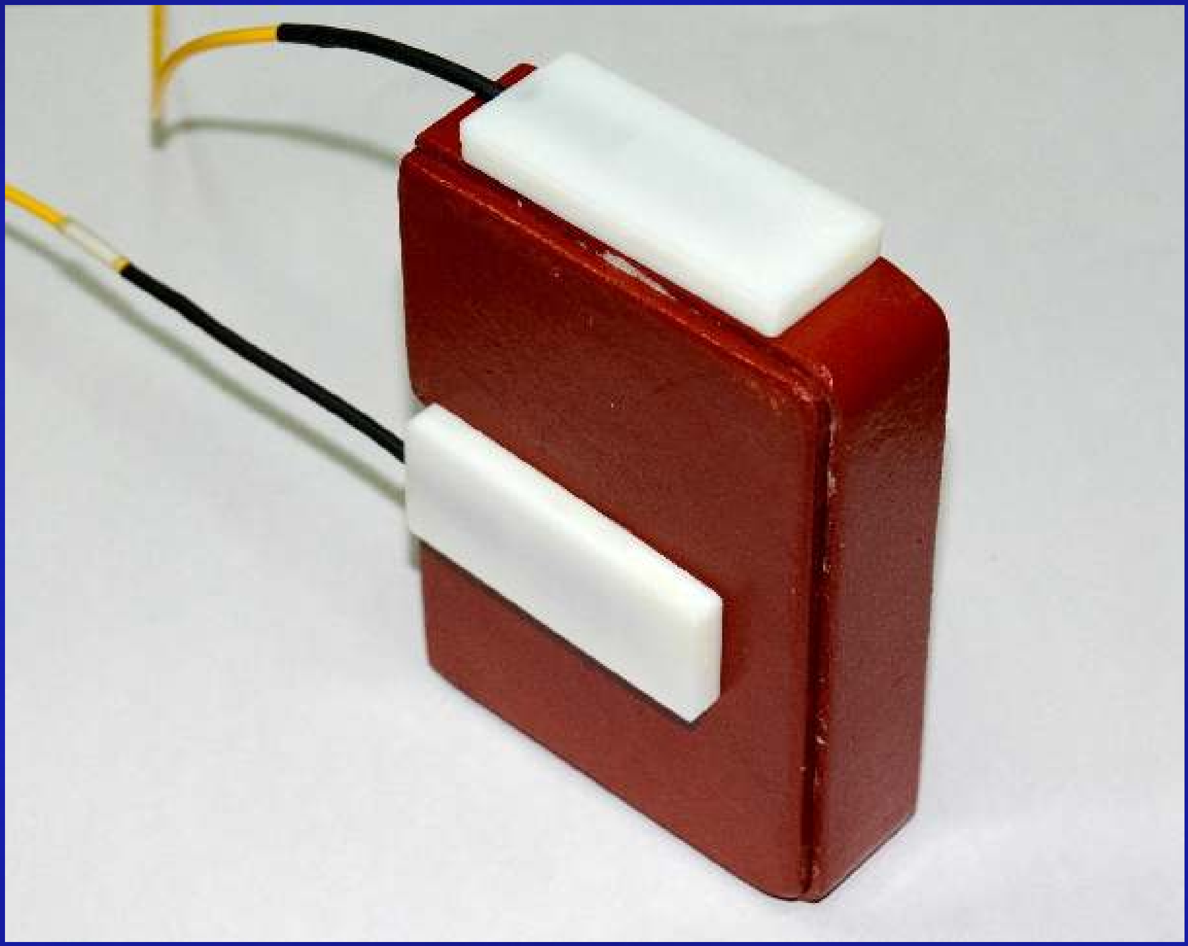
Calibration Tests carried out at 100Hz



VibroFibre™ sensor's linear and better than 10% accuracy

Sensor Orientation on Stator End Caps

- Sensors mounted on winding's end caps
- Positioned at Radial and Tangential positions
- 3 radial sensors located at 120° apart
- 1 sensor at tangential position

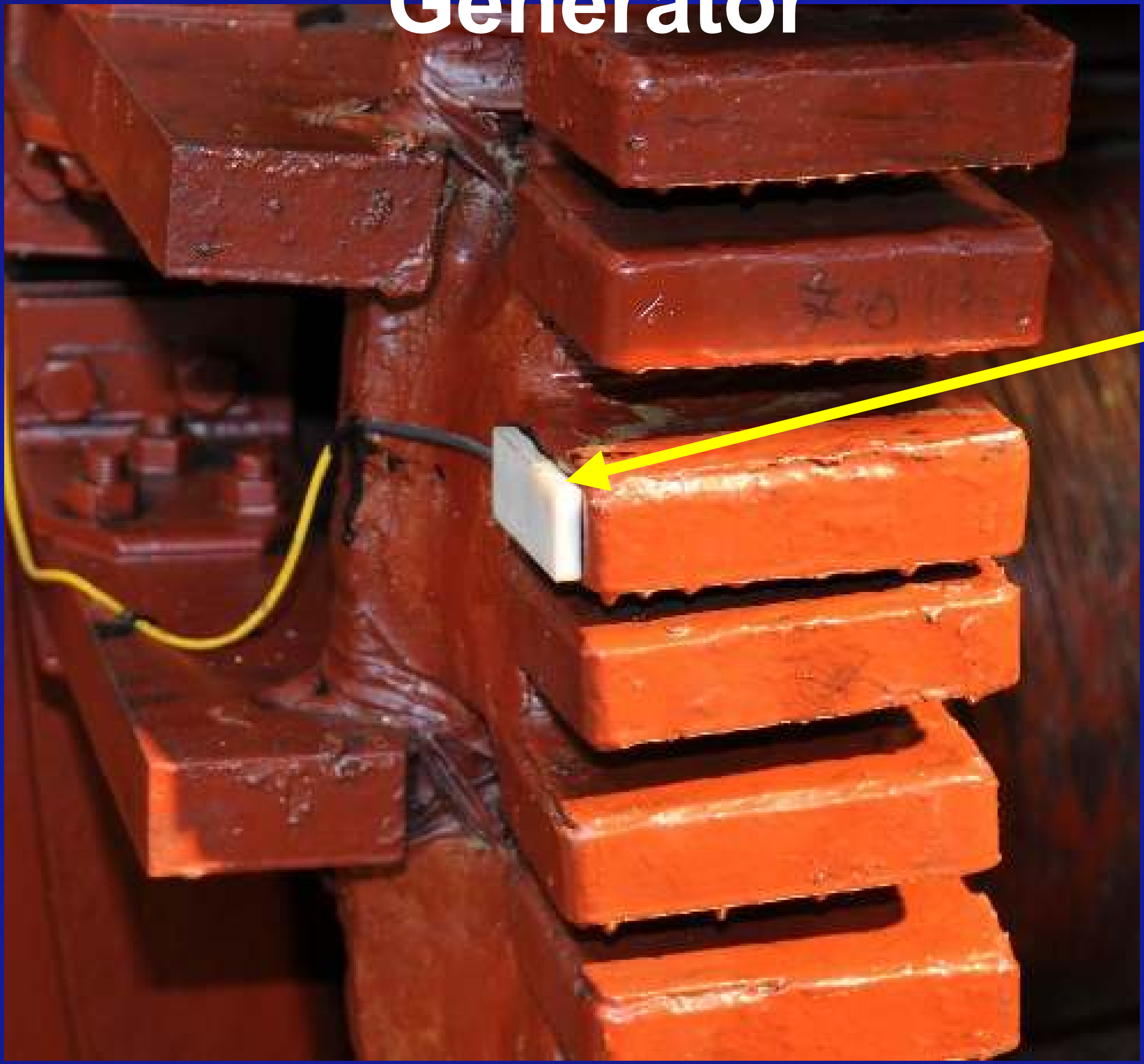


No 4 TG Generator Stator End

Covers Removed

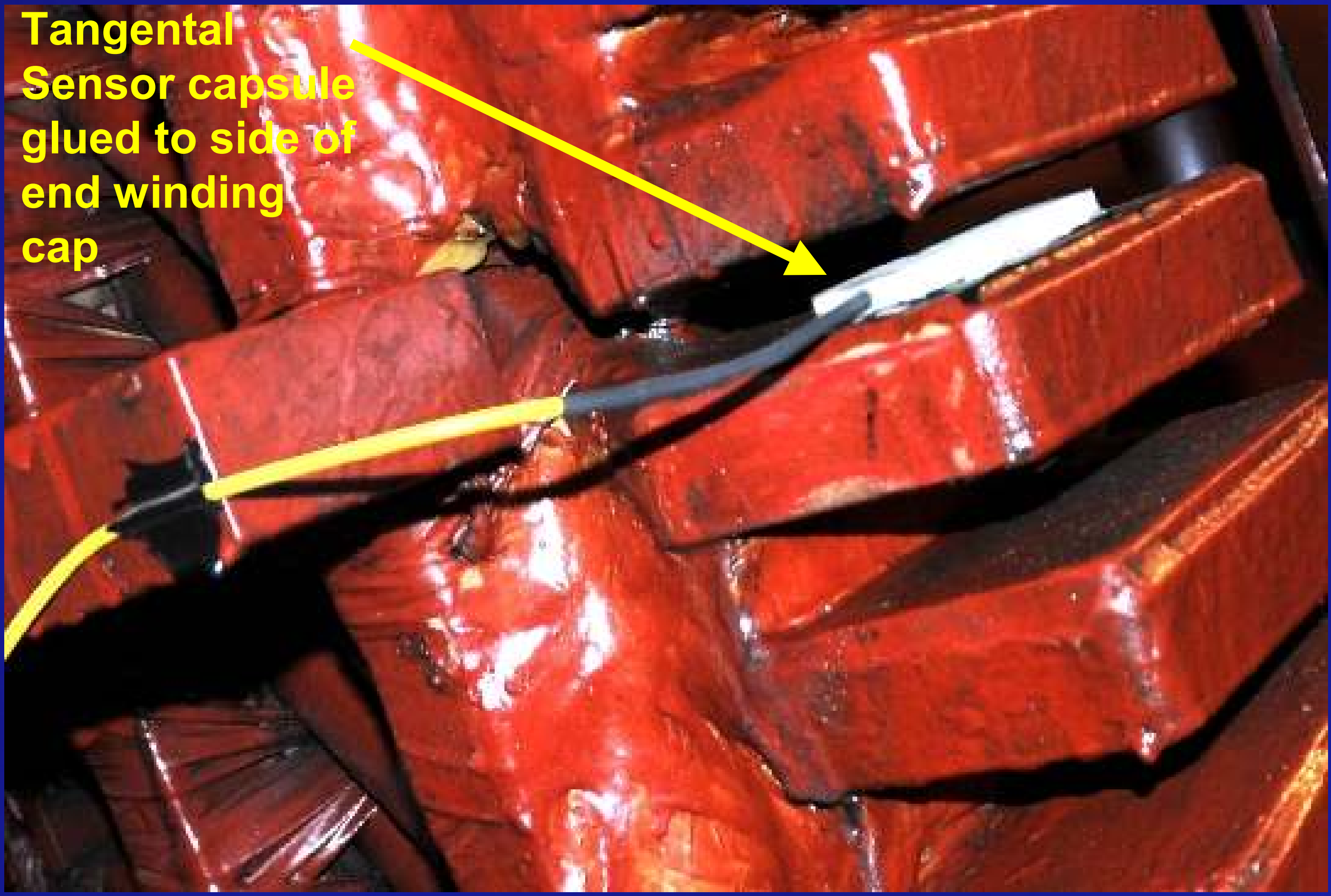


VibroFibre™ Installed on Generator



Radial Sensor capsule glued to end winding cap

VibroFibre™ Installed on Generator



FBG SEW in Operation

An Indian and World First

TG3

TG4



- MIL8800 On-Line Protection Monitors
- 4-20mA output, warning and alarm relays, RS485/MODBUS
- QPS – Data Logger & Laser Generator and Signal Processing

VibroFibre™ System Commissioning

VibroFibre™ sensor system calibration from sensor junction box through to MIL8800 monitor in the Control Room





Signal loops checks

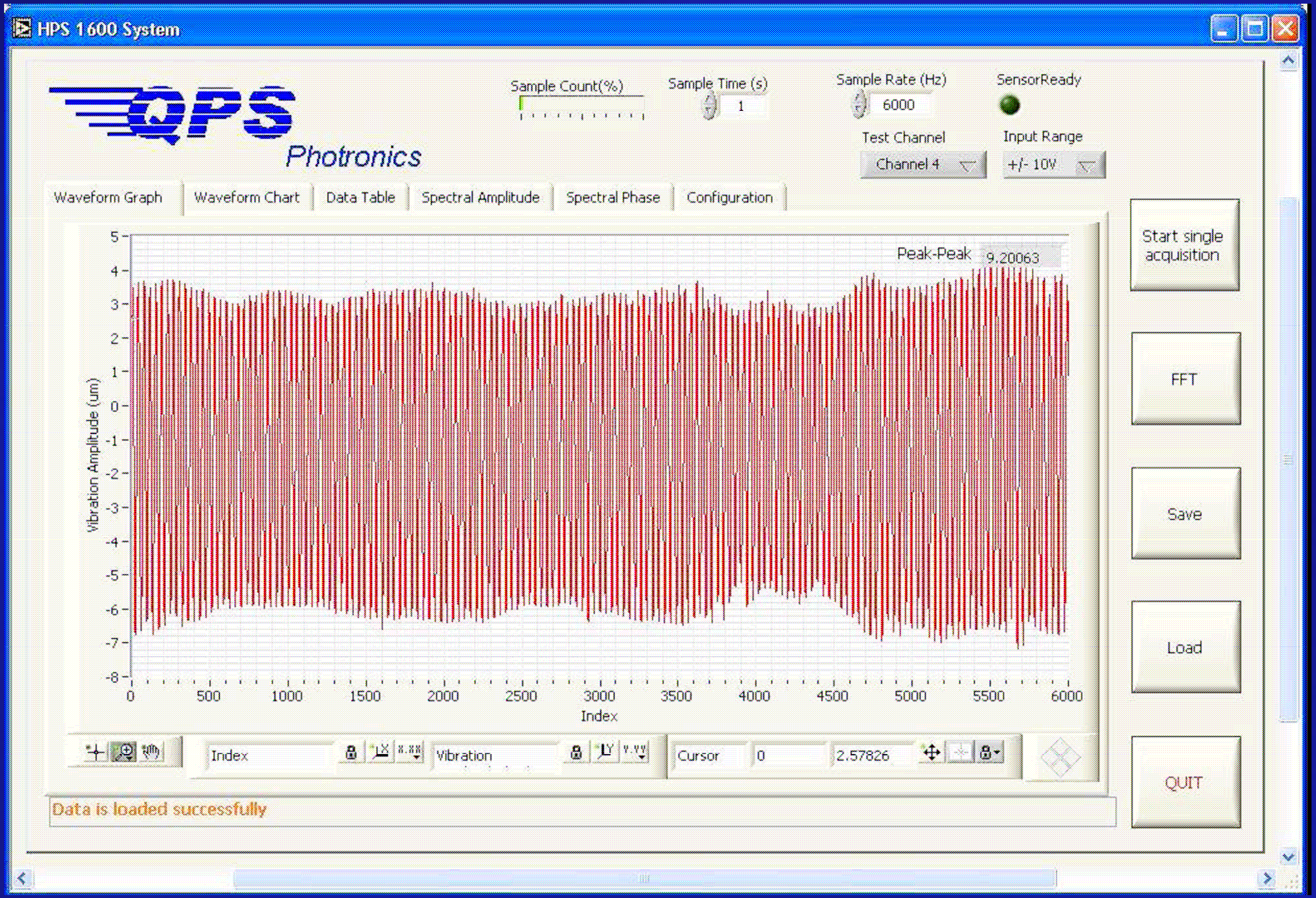
The Server provides the MODBUS communications and network for a remote PC

VibroFibre™ System Commissioning

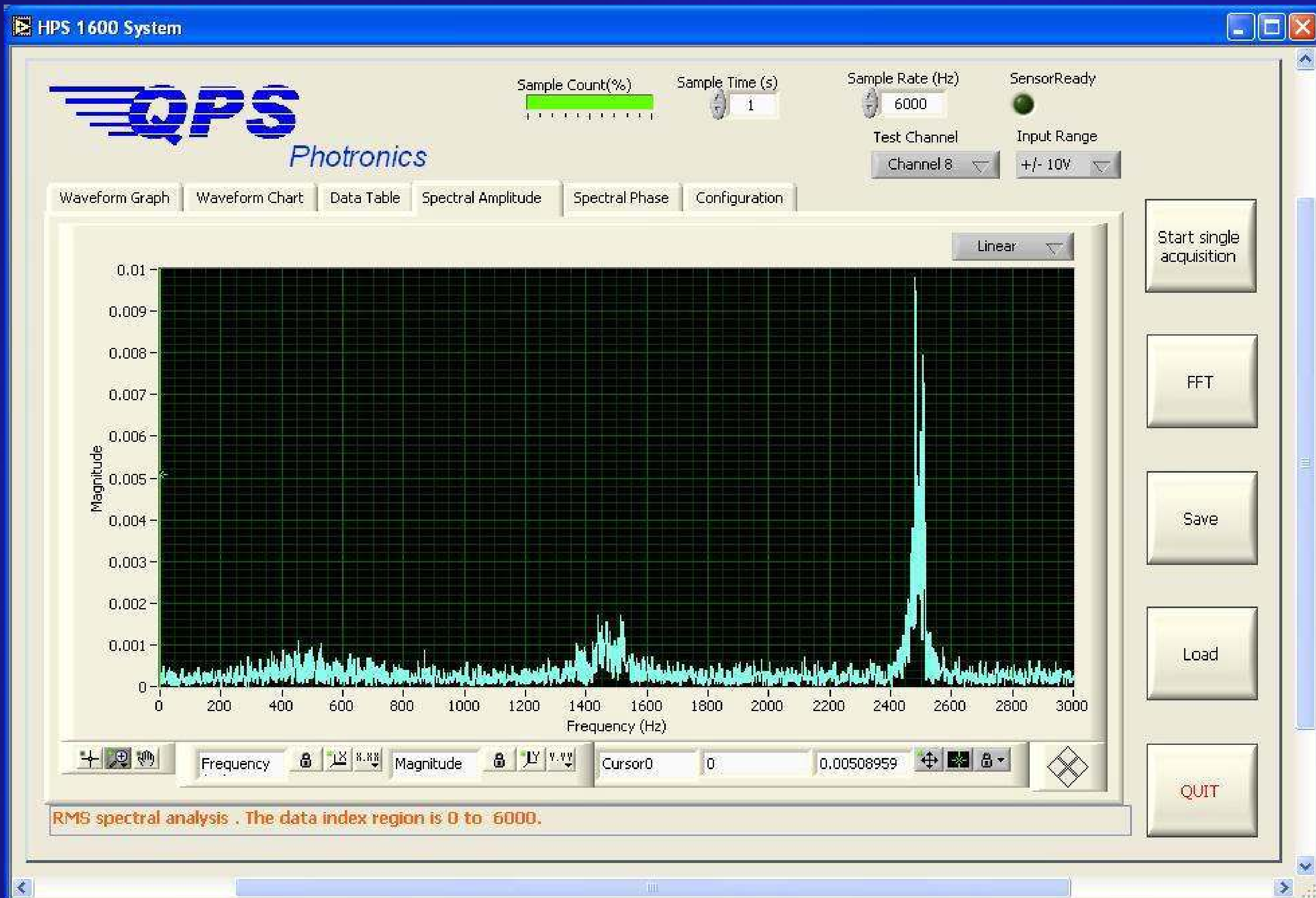


- The rear terminals of the MIL8800 VMS
- The fibre optic data logger output sockets
- A computer is used to configure sensor sensitivity across all channels
- Each signal from the VibroFibre™ sensor is verified and time waveform signal checked
- Levels are recorded against various machine operating conditions

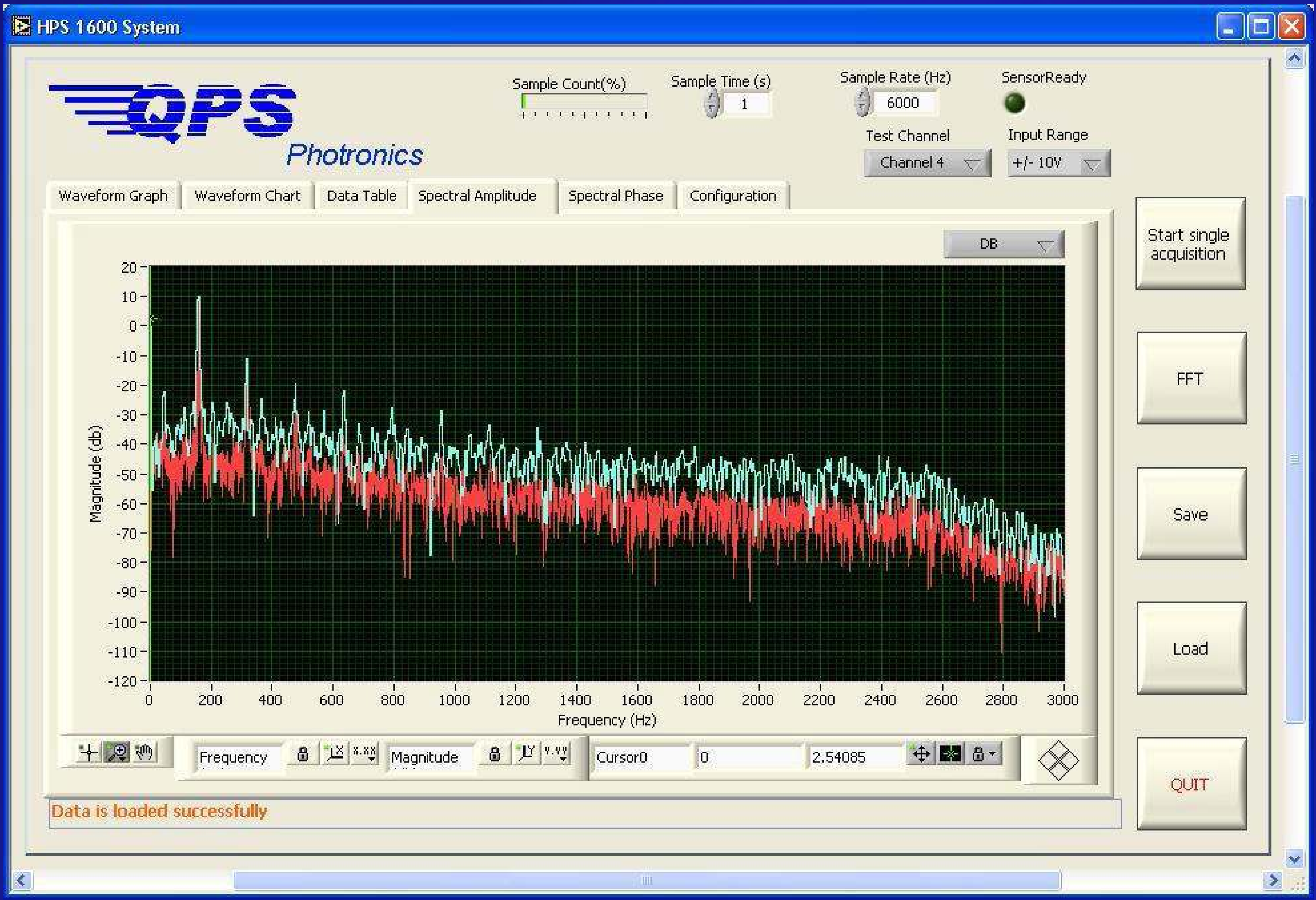
Vibration Signal Acquisition



Signal FFT Analysis



Compare Load with FFT Spectrum



Operators Warning & Alarm Station

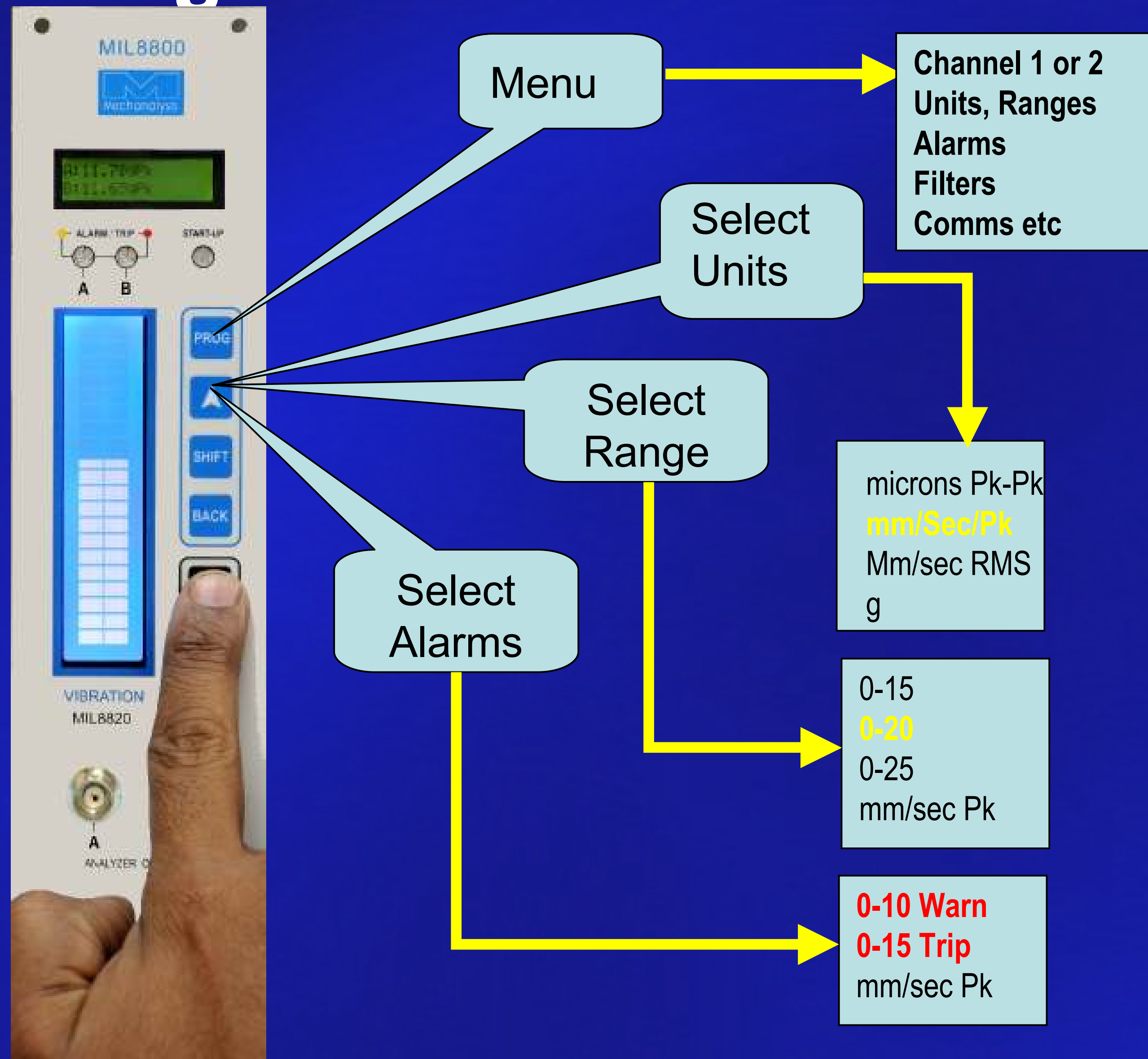
API670 Compliant from MIL – Designed and Made in India



- The MIL8800 is microprocessor based, programmable at key pad
- High and Low Pass Filters are adjustable
- Warning and Alarm relays for each channel
- Communications include isolated 4-20mA output, RS485/MODBUS
- SMPS power supply for each module, no common mode failure

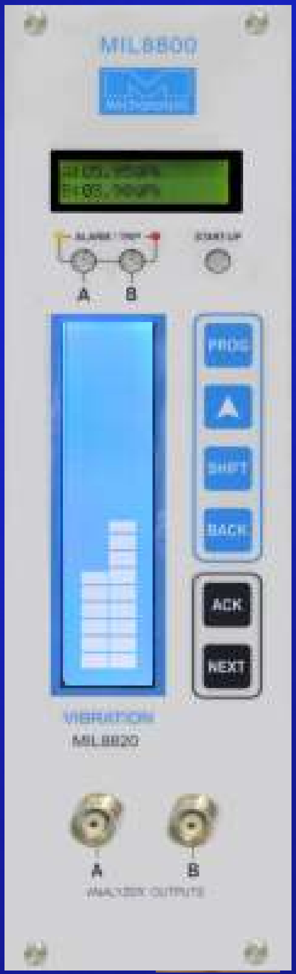
Programmable

- **Programmable**
- **Password Protected**
- **Key Pad Alarm Acknowledgement**
- **Clear Display**
- **Bar Graph**
- **Digital Display of Units**



Operator Friendly

click to start & watch



Warning Activated

Acknowledge Alarm

Back to Normal

What Others Power Companies Say:

Avoid Potential Forced Outages: GEC

- Early and accurate detection of excessive vibration in generators is key to finding problems before they turn into costly forced outages.
- A proven way to detect vibrations is to continuously monitor specific locations within a generator—such as the end-windings, high-voltage terminal leads, core punching, excitation leads and transformers, and stator bar windings.
- Results can be trended with a recorded historical database, enabling similar units to be compared.

Causes of End-Winding Vibrations: GEC

- As generators age, the end-winding support structure begins to become more compliant.
- Increased compliance heightens the forced vibration, resulting in reduced resistance to the 100 Hz
- Vibratory forces naturally found in the stator end-turn region (100 Hz for 50-cycle machines).

On-line stator vibration monitoring is not only a protection device but also a maintenance optimisation tool: Power Gen UK & EDF France

Looking Forward

- Quality, Performance, and Service are our core values. QPS wants to develop a global network of partners and associates and become a world leading provider of photonics solutions. QPS continues to be a technology innovator; co-operating and learning with our partners and customers.
- Mechanalysis is the Exclusive Distributor for QPS Photronics for Asia Pacific
- Together we are taking VMS forward in the 21st Century to greater reliability and value

QPS Photronics + Mechanalysis

World Leaders in FBG Fibre Optics for

Stator End Winding Vibration Monitoring

Thank you for your attention

condition monitoring solutions

Presentation by: Peter Kung (QPS) and Peter W. Hills (MIL)

Any errors and omissions are regretted, this is not intentional

QPS Head Office:
217 St. Louis Ave.,
Pointe Claire, Quebec
H9R 5L7 Canada

Phone: +1-(514) 697-4728
Fax: +1-(514) 697-8693

Email: info@qpscom.com

Website: www.qpscom.com

Mechanalysis (India) Limited

1/5, Marol Co-op. Industrial Estate Ltd
Off. Mathuradas Vasanji Road
Marol
Andheri (East)
Mumbai400 059

Tel: +91-022-2852 0178
Tel: +91-022-2859 6214 / 6573
Fax: +91-022-2852 1814

Email : info@mechanalysisindia.com

QPS Photronics